How to Prevent Cartridge Heater Failure and Extend Heater Life

Sponsored by: Backer Hotwatt Inc.

Cartridge heaters have insulated resistive heating elements that are encapsulated by a metal sheath. Insulation helps maximize the heat transfer rate as well as isolate the heating element from the conductive sheath. Cylindrical cartridge heaters are most common, but the cross-section of the heater may also be square, rectangular or other custom shapes.

Cartridge heaters provide localized heat to restricted work areas that require close thermal control. Typically, the heater is installed in a die, platen or other machined part that transfers the heat. In other applications, the heater is directly immersed in a fluid medium. When utilized as an immersion heater the heater's sheath must be compatible with the fluid medium it contacts and it is advised to seal the end of the heater.

Backer Hotwatt Inc. manufactures low-watt, medium-watt, and high-wattage cartridge heaters from 0.125 to 2.375 in. diameter in standard and custom shapes. The cartridge heaters are constructed either with standard heating coils that are inserted into ceramic tubes, or for high watt densities swaged cartridge heaters are available. While these look identical, the internal construction is quite different.

Cartridge heaters are constructed either with standard heating coils that are inserted into ceramic tubes. Swaged cartridge heaters are also available for higher watt densities.

Standard Cartridge Heaters

Standard cartridge heaters incorporate nickel-chrome heating coils, which are inserted into pre-formed holes within a ceramic tube. A pure magnesium oxide (MgO) filler is added to surround and support the heating elements within the holes and aid in heat transfer. These heaters also feature a heliarc-welded end cap and insulated lead wires.

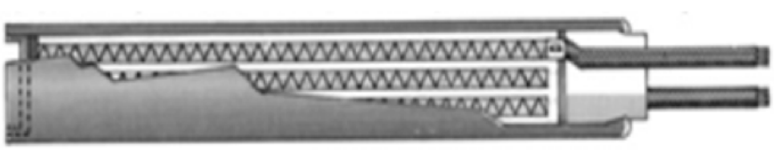

Figure 1: A standard cartridge heater. Source: Backer Hotwatt Inc.

Swaged Cartridge Heaters

Swaged cartridge heaters have a wire-wound nickel-chrome heating element wound externally around a ceramic core. This design puts the heating element in closer proximity to the heater's sheath. Pure MgO is added to isolate the element from the sheath. After assembly, the heater is then swaged and compressed to a specific diameter. These heaters offer an improved heat transfer rate, which allows for high watt densities. They can also operate at higher temperatures and endure greater shock and vibration forces without failure than standard types.

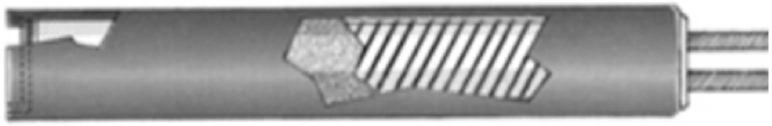

Figure 2: Swaged cartridge heater. Source: Backer Hotwatt

Causes of Premature Device Failure

Premature failure of cartridge heaters occurs either when the heat generated in the internal resistance wire is not efficiently dissipated or when moisture or foreign substance seeps inside the protective sheath, creating a short circuit. Inadequate heat dissipation results in an elevated internal temperature, which can rapidly deteriorate the heating element. This can occur when machined tolerances are outside of an accepted range, if the watt density is too high or when powered by an incorrect supply voltage.

Improper Fit

Improper fit is the most common cause of premature cartridge heater failure. The bore hole within which they are inserted must be held to tight tolerances. High watt density cartridge heaters are even more sensitive as the internal temperature of the heater can rise rapidly and jeopardize the life of the heating element. To ensure adequate thermal dissipation, the recommended hole diameter is no more than 0.002 in. greater than the nominal diameter of the heater.

Typical allowable watt densities for swaged cartridge heaters are based on fit and operating temperature.

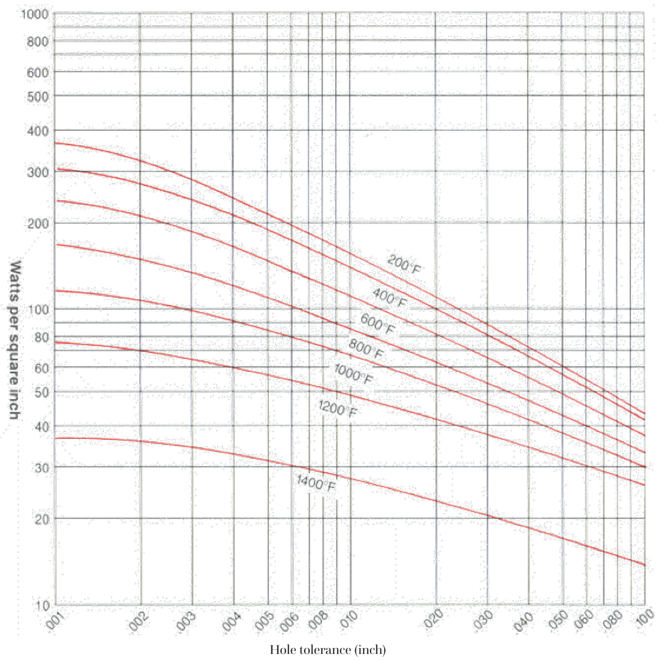

Figure 3: Maximum watt density for Superwatt swaged cartridge heaters with various increasing temperatures and hole tolerances.
Source: Backer Hotwatt

Moisture or Ingress

Even when cartridge heaters feature heliarc-welded end caps, they are prone to failure when the air surrounding the heater contains impurities or has a high moisture content and the heater's leads are not adequately sealed. This is due to the nature of MgO insulation: it is a highly hydroscopic white powdered mineral, and when the heater undergoes thermal cycling a vacuum is created, drawing in moisture or other contaminants such as oil, which can result in internal shorting.

Incorrect Watt Density

The watt density of the heater is vital to its performance. This is a measure of thermal power density and the higher the watt density, the greater the needs are for thermal dissipation. High watt densities can lead to premature failure when thermal dissipation needs are not met, as the internal temperature of the heater will exceed the limits of the resistive heating element.

Incorrect Supply Voltage

In a resistive circuit, since the resistance is fixed, when the voltage is doubled, the current doubles as well as quadrupling the wattage output. Incorrectly specifying the supply voltage can lead to premature heater failure, as voltage has a dramatic effect on the wattage and the amount of heat generated as can be seen in the following formula.

$$W_2 = W_1\left(\frac{E_2}{E_1}\right)^2$$

$E_2 = new\ voltage$
$E_1 = original\ voltage$
$W_2 = new\ wattage$
$W_1 = original\ wattage$

Backer Hotwatt has over 65 years of experience designing resistive heating elements. They provide a wide range of termination options and sheath materials with the ability to supply sealed units. They have extensive knowledge in designing heaters as an original equipment manufacturer (OEM) and can design a thermal solution that best suits the application.

Watt Density Selection and Thermal Cycling

Suggested watt density is based on several factors including the fluid medium to be heated, the desired operating temperature and process variables such as flow rate. In general, operating temperature is inversely related to the suggested watt density. Additional considerations are taken when heating a fluid to a point near its boiling point, as phase changes drastically reduce its heat transfer capabilities. Highly viscous fluids or fluids that tend to coke or carbonize also require a low watt density. Highly corrosive solutions also need a low watt density, as the increased watt density increases the potential for corrosion, drastically reducing the life of the heater's sheath.

Selecting an incorrect watt density can have adverse effects to the response of a thermal system, but it is not the only factor to consider. There are four basic elements to any thermal system, including the thermal load, the heat source, the heat transfer device and the temperature controller.

Thermal power delivered by a heating element is a function of wattage, and a correctly sized heating element will provide an ideal thermal response without rapid cycling of the element. The optimal wattage results in a 50/50 off/on cycle, which prevents or minimizes hunting or temperature overshooting. For more precise thermal control, variable voltage devices or solid-state controllers may be used.

Heated material	Max. Operating Temp.°F	Max. Watts Per Sq. In.*
Acid solutions		
-Acetic	212	40
-Chromic (5%)	Boiling	40
-Citric	Boiling	40
-Ferric Chloride (40%)	Boiling	40
-Hydrochloric	150	30
-Nitric (50%)	Boiling	40
-Sulphuric	Boiling	30
Alkali & selected oakite cleaning solution	212	40
Asphalt binder, tar, other viscous compounds	200	8
	300	7
	400	6
	500	5
Caustic soda		
-2%	210	45
-10%	210	25
-75%	180	25
Coffee	Boiling	90
Dowtherm A®		
- flowing at ≥1 ft./second	750	22
-non-flowing	750	10
Ethylene glycol	300	30
Fuel oils		
-Grades 1 & 2 (distillate)	200	22
-Grades 4 & 5 (residual)	200	13
-Grade 6 & Bunker C (residual)	160	8
-Gasoline, kerosene	300	20
Glue, heating indirectly using water bath lead stereotype pot	600	35, on casting
Liquid ammonia plating baths	50	25
Lubrication oils		
-SAE 10, @ 130° F	250	22
-SAE 20, @ 130° F	250	22
-SAE 30, @ 130° F	250	22
-SAE 40, @ 210° F	250	13
-SAE 50, @ 210° F	250	13

**Some oils contain additives that will boil or carbonize at low watt densities. Where oils of this type are encountered, a watt density test should be made to determine a satisfactory watt density.*

Heated material	Max. Operating Temp.°F	Max. Watts Per Sq. In.*
Metal melting pot	500 to 900	20 to 27
Mineral oil	200	20
	400	16
Molasses	100	2 to 3
Molten salt bath	800 to 950	40
Molten tin	600	20
Oil draw bath	600	20
	400	24
Paraffin or wax	150	16
Photographic solutions	150	70
Plating solutions		
-Cadmium plating		40
-Chrome plating		40
-Copper plating		40
-Nickel plating		40
-Tin plating		40
-Zinc plating		40
Salt Bath	900	30
Sea Water	Boiling	90
Sodium cyanide	140	40
Steel tubing cast into aluminum	500 to 750	50
Steel tubing cast into iron	750 to 1000	55
Heat transfer oils, flowing at ≥1 ft./second	500	22
	600	22
	650	22
	750	15
Trichloroethylene	150	20
Vapor degreasing solutions	275	20
Vegetable oil (fry kettle)	400	30
Water (process)	212	60
Water (washroom)	140	80 to 90

**Maximum watt densities are based on heated length and may vary depend-ing upon concentration of some solutions. Watt density should be kept as low as possible in corrosive applications since high watt densities accelerate corrosive attack on element sheaths. Consult factory for limitations.*

Figure 4: Table of suggested watt density based on the material being heated and the maximum operating temperature. Source: Backer Hotwatt

Additional considerations should be given to sensing element placement. In applications where the thermal load is relatively steady, the sensing element should be located closer to the heat source, while highly variable thermal demands are best identified by placing the sensing element near the work area.

Device selection is equally as important as the physical make-up of the system. Proper heat and load configurations, heat transfer medium or devices and feedback loops are all essential in the design of a reliable and effective thermal system.

Close Fit Tolerances

Close fit tolerances are the single most important factor affecting the heat transfer rate and the life of the heating element. A close fit allows users to achieve high efficiencies while keeping the heating element as cool as possible. Additional care should be taken when finishing or reaming drilled or cast holes to ensure a smooth surface that increases contact surface area between the heat transfer device and the cartridge heater.

To calculate the expected heater life, the heat sink operating temperature, the temperature drop across hole fit and the internal temperature are summed in order to estimate the internal wire temperature.

Empirical Guideline for Cartridge Heater Life

1. Record block operating temperature. 1. ____________
2. Determine heater density-watts/square inch: ____________
3. Determine heater fit in block: ____________
4. From Figure 6 determine the Delta T (Temperature drop) across block hole. 4. ____________
5. From Figure 7 determine the heater internal Delta T (Temperature drop) 5. ____________
6. Add steps 1, 4 and 5 to determine approximate heater internal wire temperature. 6. ____________

7. Figure estimated heater life from internal wire temperature based on the following table.

Internal Wire temp.	Approximate Life
1200˚ F or less	years
1500˚F	2 years
1600˚F	1 year
1700˚F	3 months
1800˚F	20 days
1900˚F	Less than 100 hours

Figure 5: Expected heater life as a function of internal wire temperature. Source: Backer Hotwatt

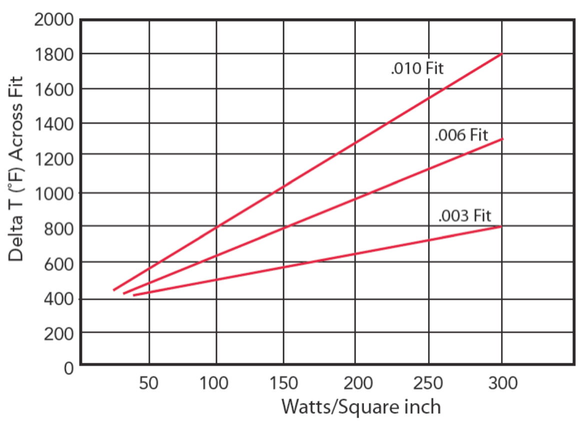

Figure 6: Temperature differential across fit as a function of watt density. Source: Backer Hotwatt

History of Backer Hotwatt Inc.

Established in 1952, Backer Hotwatt Inc. began manufacturing open coil heater elements for the appliance industry. The company has since evolved to address the needs of OEMs in industrial, medical, commercial, packaging, instrumentation, aviation, transportation, refrigeration and air conditioning and military fields.

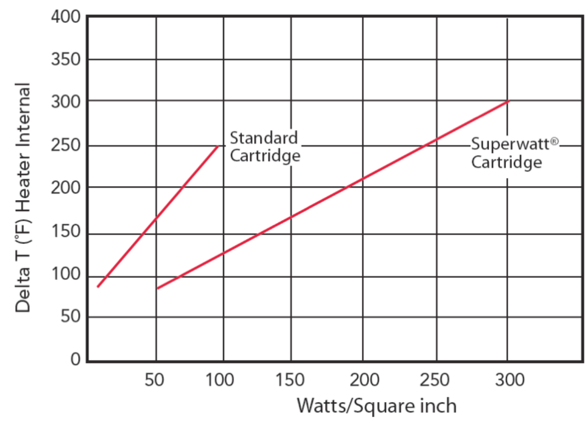

Figure 7: Internal temperature differential for standard and superwatt cartridge heaters as a function of watt density. Source: Backer Hotwatt

Hotwatt's product range has also expanded. While we specialize in low-wattage, medium-wattage, and high-wattage cartridge heaters, the company also manufactures air process, immersion, strip, tubular, band, foil, flexible glasrope, crankcase and ceramic heaters and compatible accessory items with the ability to provide complete heater solutions.

As of December 2016, Backer Hotwatt Inc. belongs to the NIBE Element North American business group. Gerteric Lindquist, president and CEO of NIBE Industrier AB stated: "The acquisition of Hotwatt adds another well-known brand to our North American Element business providing cost synergies and commercial advantages to the NIBE Group. Their market position and notable customer base will provide yet another platform for profitable growth."

Backer Hotwatt Inc. is a leading manufacturer of resistance heating elements with over 65 years of experience and is located in Danvers, Massachusetts.

Conclusion

As OEMs address critical design criteria, thermal demands have often been an afterthought. Ignoring thermal requirements can lead to limitations and obstacles that inhibit device functionality and manufacturability. Backer Hotwatt Inc. is an industry leader dedicated to the design and manufacture of resistive heating elements for OEMs. They have a wealth of industry knowledge and by engaging with Backer Hotwatt early on in the design phase, OEMs will benefit from the company's wealth of industry knowledge, with well-defined thermal device requirements and a complete heater solution developed to best suit their needs.